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Environmental Problems of Agriculture. I: Water-Related Environmental Impacts of Agriculture at the Field Level

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ENVIRONMENTAL PROBLEMS OF AGRICULTURE

I. Water-Related Environmental Impacts of Agriculture at the Field Level

by

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PREFACE

Growing world demand for agricultural production is constrained by the impacts of agricultural activity on the environment. At the beginning of 1978, IIASA's Food and Agriculture Program and Resources and Environmental Area initiated a new task, *Environmental Problems of Agriculture*. The results are to appear in a series of publications under the same title as the task itself. This is the first interim report in the series.

The task is being approached at two levels: field and regional/national. This report deals with the structure and development of water-related environmental problems at the field level. It is expected that the report will be distributed to participants of the task planning workshop to be held at IIASA on 27-30 June 1978.

ABSTRACT

The world's need to increase agricultural production leads to various impacts on the environment, some of them closely related to water processes. Water serves as a medium for transporting matter both inside and outside the given agroecosystem (a field). The water-related environmental problems of agriculture are connected with mechanical treatment of soil and use of fertilizers, pesticides, and other chemicals, and are naturally closely related to irrigation.

The components of the environment most damaged by agricultural practices are soils (due to loss of fertility) and waters (due to pollution). The water-related environmental problems of agriculture at a field level will be studied by means of simulation models. One subsystem of models describes water balance processes, and another deals with chemical compounds transported by water. Integration of the two subsystems should enhance our understanding of the problems.

The most important water-related environmental problems of agriculture, grouped in sets, are briefly discussed in this report. The sets are predetermined to a great extent by the natural conditions of the region. Some characteristics of the processes in a field are also determined by regional (zonal) features. That is why geographical analysis might be useful in the assessment and modeling of environmental problems of agriculture. A classification of natural factors that determine water-related environmental problems of agriculture is suggested. A related modeling effort for analysis of the governing natural factors is one of the principal routes to further development of the task.

Environmental Problems of Agriculture

I. Water-Related Environmental Impacts of Agriculture at the Field Level

OUTLINE OF THE PROBLEM

The world is facing quite severe shortages of agricultural products. Taking into account an expanding growth of the world's population and widespread undernourishment, mostly in developing countries, one of the main goals of mankind is to increase agricultural production. This can be done in two ways: by intensification of agriculture, and by involving new lands in agricultural activity. Of course, in reality there will be a combination of the two methods.

Intensification of agriculture implies an increase of a wide range of agricultural technology, including a shift from dry farming to irrigation, increased and improved use of fertilizers, pesticides, and other chemicals, innovations in soil treatment and measures against erosion, and the like. The use of new lands for agriculture implies a drastic shift from natural man-made geoecosystems on these lands. It is obvious that in both cases the impact on the environment would be quite pronounced.

Since the goal of constantly increasing agricultural production is long-term or even permanent, the favorable qualities of agroecosystems, such as soil fertility, cannot be wasted. Other environmental requirements must also be kept in mind; thus the quality of the physical environment is a very important constraint.

In view of this, a task on Environmental Problems of Agriculture has been started at IIASA (in January 1978). It is a joint task for the Food and Agriculture Program and the Resources and Environment Area. One of its points of departure is the task force meeting on Ecological Sustainability and Improvement of

Agroecosystems held at IIASA in April 1977. The meeting elaborated the following list of environmental problems of agriculture.

A. Physical Factors of the Environment

I. Water

a. Salinization and regimes of underground water
   1. Salinization
   2. Waterlogging
   3. Lowering of water tables
   4. Loss of irrigation water

b. Watershed management
   5. Loss of water control
   6. Water erosion of soil
   7. Siltation of reservoirs

c. Water quality
   8. Irrigation water quality
   9. Fertilizer runoff and leaching; eutrophication and effect on human health
   10. Runoff of pesticides and similar agricultural chemicals
   11. Waterborne diseases: schistosomiasis, etc.

d. Land reclamation
   12. Land reclamation, including drainage and antidrainage

II. Soils

e. Erosion: wind and water
   6. Water erosion of soil
   13. Wind erosion of soils

f. Desertification
   14. Desertification

g. Chemical pollution of soil
   15. Soil oxidation, especially of acid sulfate (e.g. mangrove) soils
   16. Toxic chemicals in soil, especially as result of mining activities

h. Soil structure, fertility, and composition
   17. Soil compaction
   18. Soil structure and fertility

III. Atmosphere and Climate

i. Atmospheric effects
   19. Air pollution

j. Climatic effects
   20. Climatic perturbations
   21. Climatic change

B. Biological (Population and Community) Factors of the Environment

IV. Pest and Weed Management

k. Pests
22. Pest attack
23. Pesticide resistance

l. Weeds
24. Weed attack and control

V. Conservation

m. Conservation
25. Loss of genetic resources
26. Loss ofnatural habitats
27. Loss of arable land to other uses.

The task is developed at two levels: a field level and a regional/national level, with a view to integration of the two. A field is a unit where many natural processes can be studied in their relations to agricultural technologies and to the environment. Processes in a field can often be regarded as horizontally homogeneous, which simplifies many problems. And, after all, the field is a primary unit for agricultural activities; without understanding what happens on a field, a formulation of agricultural policy is rather difficult.

Among the environmental problems of agriculture, water-related problems occupy an important place. It can be said that water is the blood of an ecosystem. Water not only influences the plant's growth *per se*, but serves as an important medium of transfer for nutrients, salts, etc., in soils. It influences also the physical properties of soils, both directly and indirectly due to biochemical processes. And, finally, water is a medium of compound exchange between a given field and the surrounding environment.

This is why, from the multitude of environmental problems of agriculture and the various hierarchical levels of their study, we have chosen water-related problems at a field level. Note that problems concerning only water use in agriculture are not discussed here (i.e. rational use of water for irrigation, or impact on water resources due to increase of yield and, hence, increase of evapotranspiration). These problems, while very important, should be examined separately.

PRINCIPAL WATER-RELATED IMPACTS OF AGRICULTURE ON THE ENVIRONMENT

A conceptual scheme of an agroecosystem and its relations to man's activity and nature is shown in Figure 1. The block of Agricultural Activity describes a set of man's various influences on the agroecosystem. The latter consists of three main subblocks: Soil, Plant, and Pest. In this study the pest/plant relations will not be treated; they require a different, quite complicated approach. Agricultural Activity not only changes the conditions of the agroecosystem, but also has an influence on Environmental Quality. In the Agroecosystem block, emphasis will be placed on the biogeochemical processes in soils in order to assess changes in soil fertility. The influence of Agricultural Activity at the field level on the outer environment can

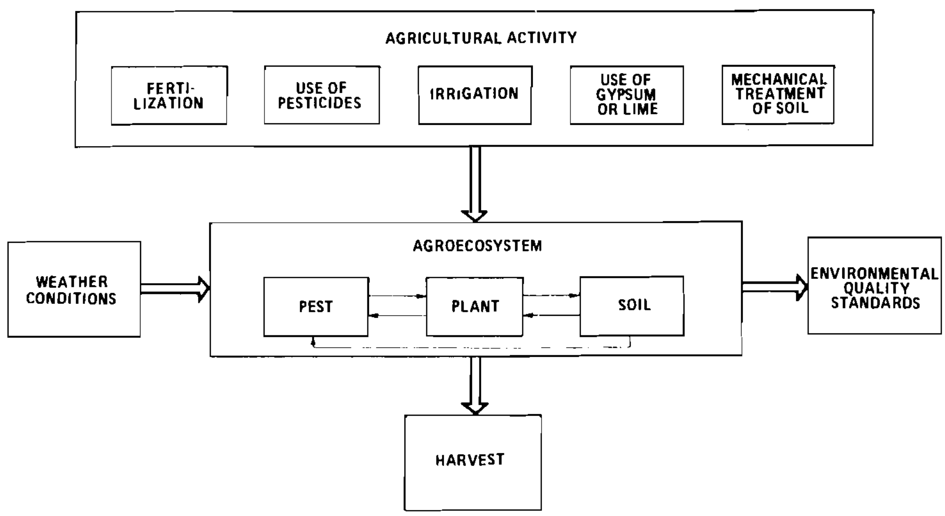


Figure 1. Agroecosystem and its relations with the outer world.

be considered through inputs of various components contained in the water that reaches the primary hydrographic network and groundwater.

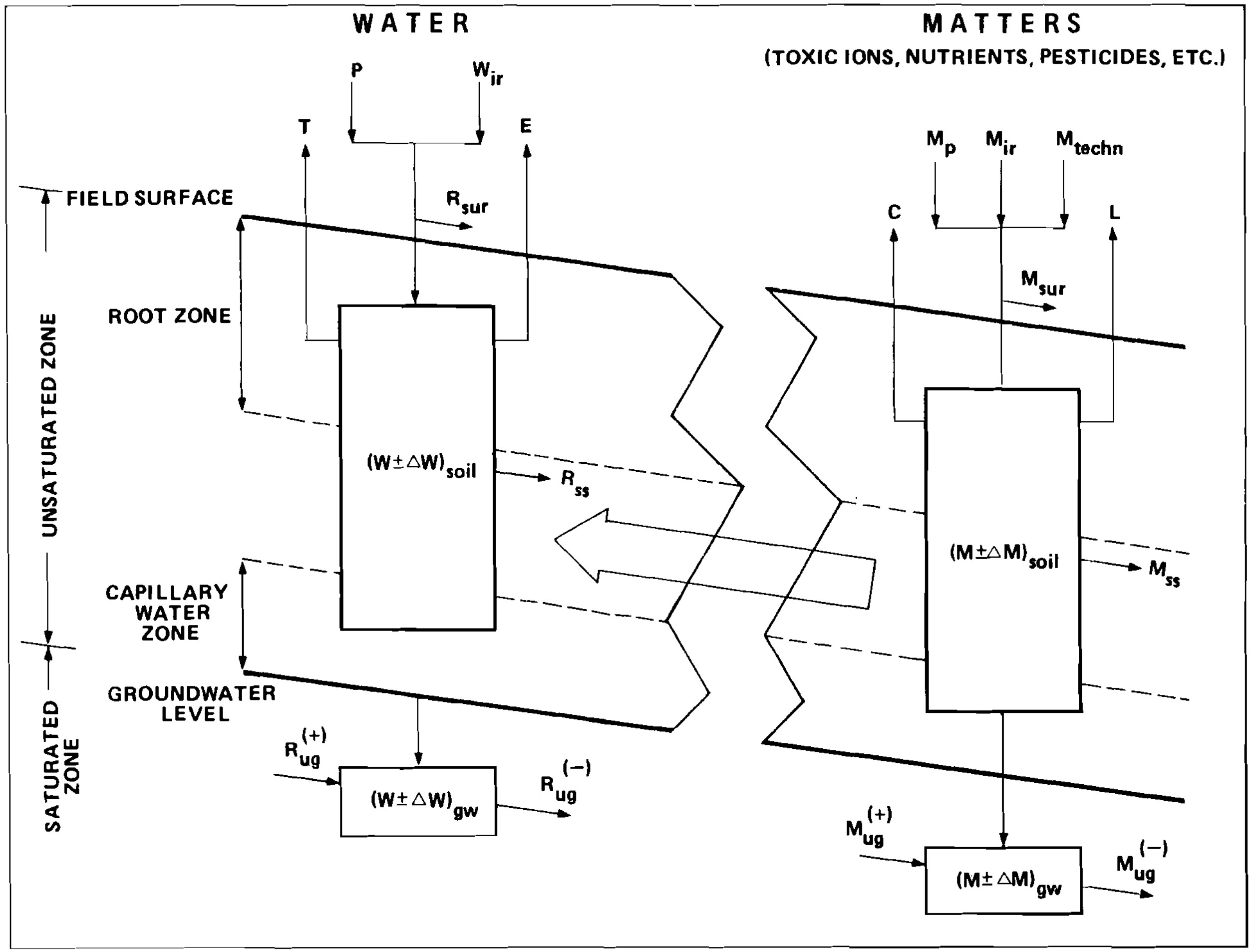
Figure 2 shows a conceptual scheme of the principal water-related processes at a field level. Since, in the processes in which we are interested, water serves mostly as a transporting substance, the right part of the figure should be regarded as superimposed on the left part. The boundaries of groundwater, capillary water, root zone are not constant with respect to time. The upper boundary of the capillary water zone and the lower boundary of the root zone are in reality not strict surfaces (planes in a three-dimensional space) but transitional layers.

The relations and processes shown in Figures 1 and 2 lead us to the principal water-related environmental problems of agriculture in their dependence on types of agricultural technology and impacts on the environment (Figure 3). This scheme will serve as the basis for further development of the task at a field level. Let us now briefly discuss the principal environmental problems shown in Figure 3.

P. Crosson and K. Frederick, the authors of a recent survey of the world food situation [1], consider *water erosion* the most serious of the environmental agricultural problems. This problem would grow if new land now serving other uses were to be cultivated. In our view, the possibility of ranging the principal environmental problems in order of importance is questionable; in any case, it is evident that water erosion is among the most serious.

In the USA, for example, 2.7×10^9 t of soil from agricultural and forest lands are eroded by water annually. Moreover, more than one third of the cropland "...suffers soil losses in excess of the amount believed consistent with maintenance of soil productivity over the long run" [1, p. 181].

Water erosion has a number of environmental impacts: loss of fertile topsoil, which is dangerous where the rate of topsoil



P IS PRECIPITATION

W_{ir} IS WATER FOR IRRIGATION

R_{sur} IS SURFACE RUNOFF

R_{ss} IS SUBSURFACE RUNOFF

T IS TRANSPIRATION

E IS PHYSICAL EVAPORATION

$(W \pm \triangle W)_{soil}$ IS WATER CONTENT AND ITS CHANGES IN NONSATURATED ZONE

$(W \pm \triangle W)_{gw}$ IS WATER CONTENT AND ITS CHANGES IN SATURATED ZONE

R_{ug} IS UNDERGROUND RUNOFF IN SATURATED ZONE; SIGNS (+) AND (−) MEAN INCOME AND OUTCOME OF THE UNDERGROUND RUNOFF

M_p, M_{ir}, M_{techn} ARE INCOME OF A MATTER WITH PRECIPITATION, IRRIGATIONAL WATER, AND DUE TO AGRICULTURAL TECHNOLOGY CORRESPONDINGLY

M_{sur} IS OUTCOME OF A MATTER ALONG THE SURFACE

M_{ss} IS MOVEMENT OF A MATTER WITH THE SUBSURFACE RUNOFF

C IS CONSUMPTION OF A MATTER BY PLANTS

L IS LOSSES OF A MATTER INTO AIR

$(M \pm \triangle M)_{soil}$ IS A MATTER CONTENT AND ITS CHANGES IN NONSATURATED ZONE

$(M \pm \triangle M)_{gw}$ IS A MATTER CONTENT AND ITS CHANGES IN SATURATED ZONE

M_{ug} IS MOVEMENT OF A MATTER WITH WATER IN SATURATED ZONE

THE ARROW INDICATES THAT THE RIGHT PART SHOULD BE SUPER-IMPOSED ON THE LEFT ONE

Figure 2. Conceptual scheme of water-related environmental processes of agriculture at a field level.

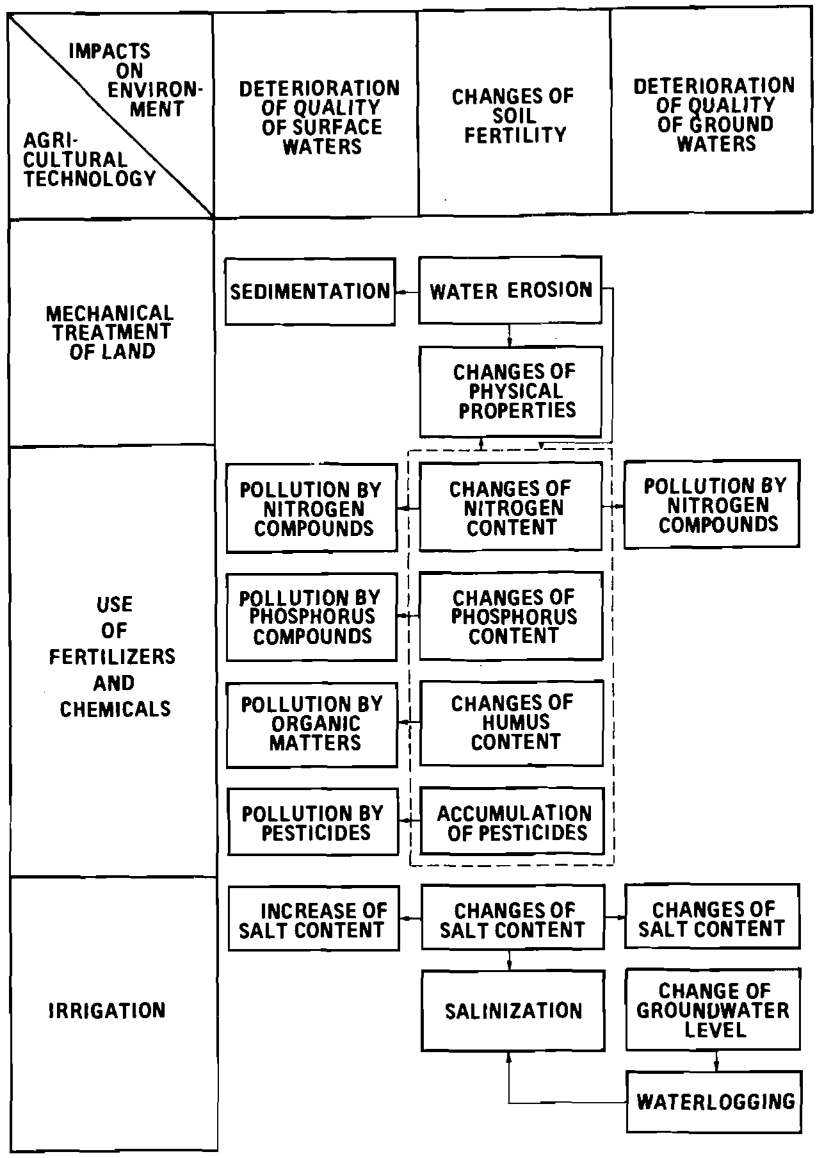


Figure 3. Principal water-related environmental problems of agriculture.

regeneration is less than the rate of erosion; siltation of natural and artificial (canals, reservoirs, etc.) water systems; and transport of chemical compounds absorbed by surface soil particles or accumulated in the topsoil. The last-named process, typical for phosphorous fertilizers, organic substances, pesticides, and other compounds, leads to deterioration of quality of surface waters.

Use of fertilizers is necessary to increase crop yield. There is a pronounced trend toward increasing fertilizer use.

In the USA, fertilizer consumption rose from 5 Mt in 1950 to 16.3 Mt in 1975, and the use of nitrogen during this period increased by more than five times [1]. In the same period, production of nitrogen fertilizers in the USSR increased by more than 20 times [2]. Worldwide, the use of fertilizers in Mt is as follows [3]:

1952	1972	1980	2000 (forecast)
21	79	150	270

This tendency leads to an increasing impact on the environment, above all on the quality of natural waters. In this respect, the behavior of the principal types of fertilizers differs.

Potassium fertilizers seem to have no noticeable influence on the environment and are not discussed here. The behavior of *nitrogen* and related fertilizers is very complicated and depends on many factors, both natural and technological. Nitrogen in soils appears in organic form, in ionic form (ammonia, nitrite, and nitrate), and in gaseous form, and these forms interconvert. Ionic forms of nitrogen are quite soluble and can be easily carried into water bodies by all kinds of runoff (surface, subsurface, underground). Even small concentrations (over 0.3 mg/l) increase algal growth, and hence eutrophication of water bodies. There are also many cases when, due to agricultural activity, the concentration of NO_3-N in natural water becomes too high. The World Health Organization recommended that the concentration of NO_3, expressed in N, in drinking water should not exceed 11.3 mg/l, while concentrations higher than 22.6 mg/l are unacceptable. These are values for countries with temperate climate; for tropical countries the limits are lower.

Nitrogen leaching occurs even when no fertilizers are used. G. Cooke [4] in his excellent review of these problems in Britain indicates that, according to lysimeter experiments in Rothamsted on soils never cropped or fertilized, the mean annual NO_3-N leaching for 27 years was 9.8 mg/l. He also points out that drainage waters from intensively managed arable land often contain a yearly average of 10 to 15 mg/l of NO_3-N, with larger concentrations over a period of years, particularly when plant activity is reduced. These facts do not mean that it is impossible to meet the standards mentioned, as complex processes occur in water bodies entered by drainage waters from agricultural fields. These affect the quality of the water finally formed, which may conform to existing standards.

Compounds of *phosphorous* are much less soluble than those of nitrogen. Soil solutions contain very small concentrations of phosphate [4], and the threat of phosphorous leaching is usually insignificant. The main factor in transporting phosphates--both naturally occurring and in fertilizers--into surface waters is erosion. According to Cooke [4], many cultivated soils have about 0.1 percent P. With a soil erosion rate of 1 mm/yr, 10 kg of phosphorous per hectare is removed by water running over the surface even where no phosphorous fertilizer is used. When it is added, some part of it is removed with surface runoff. In the USA, annual losses of P by erosion are estimated at 6 kg/ha, or 60 percent of the fertilizer used (Holt et al., 1970, cited in Cooke [4]).

The growth of cultivated plants without proper agricultural technology often leads to a decrease in the *humus content* of soils. The humus significantly influences both plant nutrition and important *physical properties of soil*, such as its structure. One way of retaining and increasing the humus content is the use of manure as fertilizer. In the USSR in 1975, no less than half of all fertilizers applied was in the form of manure [2]. In the USA, this proportion is about three times lower [5]. The authors of *Control of Water Pollution from Cropland* remark: "The pollution potential from using manure with poor management can be substantially higher than that from using commercial fertilizers, because nearly all manure is spread on the soil surface and can contain large amounts of soluble carbon, nitrogen, and phosphorous compounds" [5, Vol. 1, p. 37].

Pesticides are widely used in agriculture all over the world. In the USA, the major user, farmers applied 220,000 t in 1971 [5]. On the average, pesticide application is 0.24 kg/ha in the USA, 0.30 kg/ha in Europe, and as much as 1.74 kg/ha in Japan. In the developing countries the amounts are generally ten times lower [5]. The U.S. President's Science Advisory Committee estimation (cited in [5]) is that every dollar spent for insecticides returns five dollars to the farmer. The use of pesticides is increasing constantly, and this tendency will persist.

At the same time, pesticide use leads to an unfavorable increase in the soil of chemicals that did not occur before in the natural environment and food chains. It is difficult to discuss the threat of this phenomenon in general terms; in the USA alone, the current domestic market for pesticides includes more than 1800 biologically active compounds sold in over 32,000 different formulations [5] whose behavior varies greatly. The rate of pesticide degradation ranges from several years (for example, for DDT, which has been banned in many countries) to several weeks or months. What can be said in general terms is that the pollution by pesticides is low for the volumes applied. Measurements in a number of regions of the USSR show that less than 2 percent of pesticides applied have been detected in drainage waters from agricultural fields [6]; and in the USA, less--often much less--than 5 percent of pesticides runs off the land during the crop year [5]. Nevertheless, even these low concentrations can be toxic, especially in the long term, and should therefore be taken into consideration.

Pesticide accumulation, degradation, and movement should be considered in a context of natural factors and agricultural technology. The behavior of pesticides is governed to a great extent by sorption on soil particles, by solution of water, and by equilibrium of sorption and solution. Surface runoff and erosion represent the main threat, carrying off water-soluble compounds and pesticides in soil particles, respectively. Groundwater pollution by pesticides usually is not significant.

All the processes mentioned have an impact on the *physical properties of soils*. Of the many properties determining fertility, structure is one of the most important. Conversely, physical properties (structure, permeability, water-holding capacity, etc.) have a considerable influence on the processes discussed.

Specific environmental problems are encountered with irrigation. When additional amounts of water are applied to a field, the natural balance of water and salts in the soil is disturbed. Usually, a change in water balance leads to a rise in groundwater and capillary water levels. If the salt content in the soil is not high for the plant, and the capillary water zones (but not the groundwater zone!) reach the plant roots, this favors the plant's development. However, in areas that require irrigation, the salt content in soils is usually quite high. Additional water dissolves some of these salts and moves them downward. In many cases, this leaching of salts from the root zone first leads to an increase in yield. The groundwater in arid regions, being already rich with salts, receives additional amounts; if the capillary water level reaches the plant roots and its salt content is higher than optimal for plant growth, then the yield decreases. Thus problems of *soil salinization* and *waterlogging* are often inseparable. Worldwide, about 230 to 240 $\times 10^6$ ha are irrigated, and a large part of that area has soil salinization problems [7]. Problems of dry farming agriculture, discussed above, also exist there, superimposed on typical environmental problems of irrigation.

Another result of irrigation is that agricultural drainage waters transporting salts enter normal river water and increase its salt concentration, often to the point where further withdrawals are impossible. The example of the Colorado River in the USA is well known. The same problem is starting to develop in the lower reaches of the Syrdaria River in Soviet Central Asia.

The specific chemical composition of irrigated water and/or soils may cause special problems. The most common is *alkalinization* or sodium salinization: sodium pushes other ions out of the soil absorbing complex and unfavorably changes the *physical properties of the soil*, making it initially unstructured. Costly treatment including the use of large amounts of gypsum is required for reclamation of such soils.

Improper use of tropical laterite soils may cause the removal of nutrients by water erosion that leads to the loss of soil fertility and to soil *compaction*.

This brief review of the principal water-related impacts of agriculture on the environment suggests the following approach:

- Each phenomenon discussed should be studied in its relation to natural factors and agricultural technology.
- In reality, we usually do not face a single process but rather a combination of them. In the most complex cases, *all* the processes shown in Figure 3 should be taken into consideration; in others, only some of them. These combinations should be studied in order to solve environmental agricultural problems.
- The natural factors largely determining the environmental problems of agriculture are not chaotically distributed over the globe, but are generally governed by some geographical laws. Agricultural technologies to a certain extent also depend on natural factors. Therefore, geographical analysis can be a useful tool in the investigation of environmental problems connected with agricultural activity.

FIELD LEVEL WATER-RELATED PROCESS RESPONSIBLE FOR ENVIRONMENTAL IMPACTS OF AGRICULTURE

Agricultural impacts upon the environment are determined by agricultural activity as well as by agroecological processes in a field. The latter are responsible for the transmission of agricultural actions to the environment. A system of simulation models describing these processes should allow us to link agricultural activity and environmental impacts.

We have discussed earlier the role of water in the processes in which we are interested. The integrated model planned will consist of two main parts, the first describing the water balance processes in an agricultural field, and the second the biogeochemical processes in soil. A conceptual scheme for water balance processes in the agricultural field is shown in Figure 4. The water input to the field includes irrigation water and precipitation; the water output includes evaporation, transpiration, surface and subsurface runoff, and deep percolation. The core of this scheme is the moisture balance in soil. At present, most equations and methods available use one-dimensional consideration of these processes in soil; but the subblock of the general scheme of water consumption by roots has to consider root growth. The transpiration mainly will be dependent on weather conditions and the root's consumption.

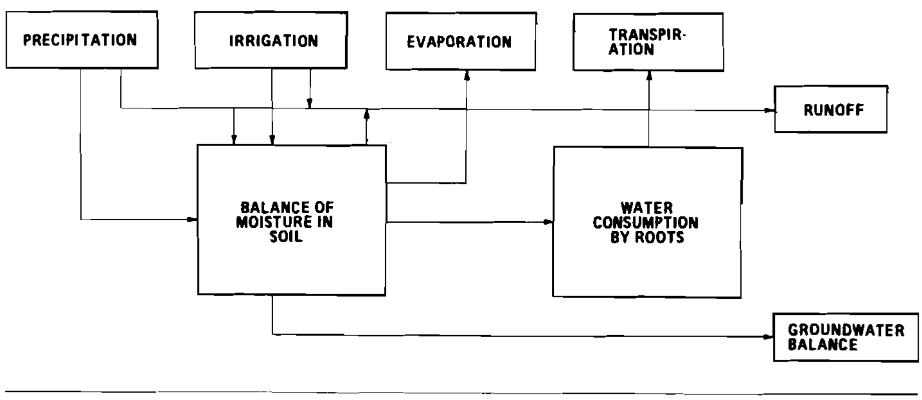


Figure 4. Conceptual scheme for the water balance processes in the agricultural field.

The conceptual scheme of the biogeochemical processes in soil (Figure 5) describes the accumulation and transformation of organic and/or mineral matter. Let us consider this scheme in detail. Each subblock represents a soil component. The arrows correspond to the biochemical and physicochemical soil processes. Plant residues and manure are the initial organic matter in soil. The microorganisms, and humus substances taken together are the organic material of the soil; in its decomposition, carbon dioxide, mineral nitrogen, and phosphorus are formed. The undissociated salts are mineral fertilizers and natural mineral salts. In the process of dissolution the salts dissociate into ions. The ions in the soil solution are in equilibrium with those in the exchange complex. The soil gas is represented mainly by oxygen, carbon dioxide, and the gas form of nitrogen.

On the basis of the two outlines (Figures 4 and 5), an integrated scheme can be conceived (Figure 6), showing the water-related processes in an agricultural field. Let us examine how

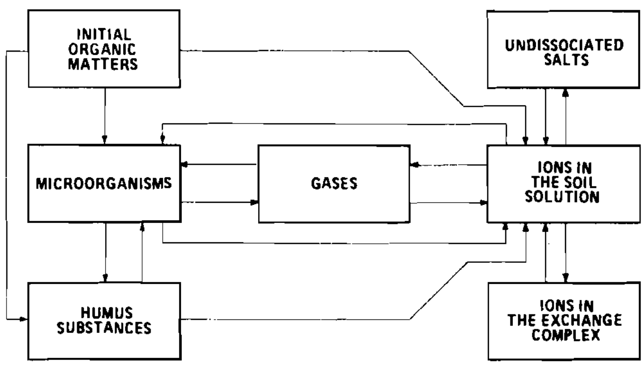


Figure 5. Conceptual scheme of the biogeochemical processes in soil.

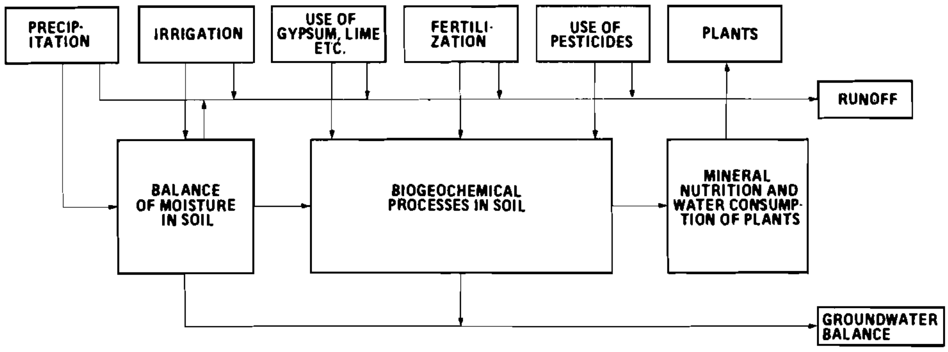


Figure 6. Conceptual scheme of the integrated simulation model.

these processes are responsible for the water-related environmental problems shown in Figure 3. Surface runoff is responsible for erosion and sedimentation in water bodies. Use of fertilizers and pesticides leads to pollution of surface waters due to surface runoff. The rise of groundwater and waterlogging are related to disturbance of the groundwater balance. The biogeochemical processes in soil cause organic and mineral matter to change from one form to another. Pollution of groundwater by nitrogen compounds is connected with leaching of nitrate-nitrogen. Changes in the main chemical soil parameters, such as content of nitrogen, phosphorus, and humus, influence soil fertility. The changes in salt content and salinization are a complex natural phenomenon depending on the balance of soil moisture and on biogeochemical processes in the soil.

The schemes shown in Figures 4, 5, and 6 are considered by us as the basis for collection, assessment, correction, and integration of the available models.

NATURAL FACTORS AND WATER-RELATED ENVIRONMENTAL PROBLEMS OF AGRICULTURE

The location of an area determines many of its natural features. The first of these is the *climate*. There is a great difference in the natural processes of, for example, northern coniferous forest and equatorial savanna. Wet equatorial forests and leaf-bearing forests of temperate climates have little in common. The processes in agroecosystems also differ from one place to another because a large part of these man-made systems is derived from the natural geoecosystem.

The geographic distribution of natural landscapes is determined to a great extent by the amount of solar radiation and the correlation between energy and water received annually by a particular surface. According to A. Grigoriev and M. Bydiko [8], the best indexes of spatial distribution of natural landscapes are the following: mean annual net solar radiation (R), and the ratio between net solar radiation and the amount of precipitation (r), expressed as the energy required to evaporate it (R/Lr, where L is the latent heat of evaporation). The distribution of principal natural geoecosystems in dependence on these indexes is shown in Table 1 in simplified form. For details, one can refer to publications by A. Grigoriev and M. Bydiko, e.g. [9, p. 150].

Each geographical zone mentioned in Table 1 is defined not only by type of vegetation but by a whole set of features, some of which are important for the problems discussed here. Among these features are: genetic type of soil, which determines some characteristics of interest to us, such as the content of humus, nutrients, salts, and microbes and the soil chemical reaction; biological productivity of natural ecosystems; amount of water available after physical evaporation of part of the precipitation; and salt content of natural waters.

Quite obviously, these characteristics determine either the type of agricultural technology used, which may affect the environment, or directly cause some environmental problems. Thus,

Table 1. Geographical zonality.

Energy: Net radiation (R) $\left[\frac{ccal}{cm^2 \cdot yr}\right]$	Availability of water: radiational index of aridity $\left(\frac{R}{Lr}\right)$					
	Excessive watering		Optimal watering	Slightly deficient watering	Deficient watering	Excessively deficient watering
	0.2-0.4	0.2-0.8	0.8-1	1-2	2-3	> 3
From 0 to 50 (subarctic and temperate latitudes)	Tundra	Predominantly coniferous forest	Leaf-bearing forest and forest-steppe	Steppe, prairie	Semidesert or temperate latitudes	Desert of temperate latitudes
From 50 to 75 (subtropical latitudes)	--	Subtropical rain forest		Dry subtropical forest and bush	Subtropical semidesert	Subtropical desert
More than 75 (tropical latitudes)	--	Wet or moist equatorial forest	Light tropical forest and wooded savanna	Dry savanna	Tropical semidesert (arid savanna)	Tropical desert

knowing the principal characteristics of the climate, we may expect a certain set of environmental problems. In this paper, characteristics due to the climate that influence environmental problems of agriculture are not discussed; this will be done in a future report. Table 2 shows some typical values of the pH, which is an index of the soil chemical reaction, and the humus content for some soils in the USSR, based on data taken from [10].

The climatic indexes mentioned also determine the principal type of agricultural activity in the area (Table 3).

The *relief* of an area studied is another important factor in environmental agricultural problems at the regional level. Water erosion itself and the associated transport of chemical compounds are determined to a great extent by the relief. As a quantitative index, we have chosen the mean height of the relief in the region.

Type of relief	Flat plain	Plain, piedmont	Hills	Mountains
Mean amplitude in m	< 20	20-100	100-500	> 500
Water erosion hazard	Little	Considerable	Strong	Severe

The degree of natural drainage of soil generally increases with the mean amplitude of relief; the more rugged the relief is, the coarser are the soils and subsoils, and the shorter is the path of water from any point to water sources.

While climate and relief determine a number of principal environmental factors at the regional level, other factors should be added at the field level. The *mechanical composition of soil and subsoil* determines the possibility of leaching for chemical compounds:

	Mechanical composition		
	Coarse	Medium	Fine
Leaching potential	High	Medium	Low

Table 2. Humus content and pH in the upper 20 cm of some soils in the USSR.

Type of soil	R	R/Lr	Humus content [%]	pH
Podzol	30	0.6	1.5-5	4-5
Brown podzol	40	0.8	2.5-5.5	5.5-6
Grey podzol	35	0.9	5-9.5	6-6.5
Chernozem	35	1.2	8-12	7
Chestnut	45	1.7	3.5-4.5	7.5
Brown	40	2.5	2	7.5
Grey	50	3	0.5-2.5	8
Red podzol	55	0.6	4-7	4.5-5

Table 3. Principal types of agricultural activity related to climatic indexes.

R/Lr	0.3-0.8	0.8-1.2	1.2-2.0	> 2.0	0.8-2.0	0.3-0.8
R $\frac{\text{ccal}}{\text{cm}^2 \cdot \text{yr}}$	20-35	30-70	30-70	> 30	> 70	> 70
Type of agricultural activity	Dry farming (+ drainage)	Dry farming	Dry farming + irrigation	Irrigation	Irrigation + dry farming	Dry farming

It is known that even phosphates that are not quite soluble are leached through sandy soil, not to mention nitrates. The water-holding capacity of soil, height of capillary water rise, and possibility of water erosion also follow from the soil mechanically.

Water erosion depends on two geomorphological factors: inclination and length of slope. Since for a single field the variation in length would be small, it is chiefly the *mean slope of a field* that determines potential water erosion: the steeper the slope, the higher the potential erosion.

The *groundwater level* is a very important factor, especially in irrigated areas. Waterlogging is an important environmental problem, and secondary salinization of soils usually occurs in arid regions as a consequence of waterlogging. The groundwater level (GW) can be measured in terms of plant root (PR) depth:

	Depth of groundwater level			
	GW < PR	GW $\simeq$ PR	GW > PR	GW >> PR
Waterlogging & salinization hazard	Severe	Strong	Possible	Unlikely

Finally, there are local geochemical factors that predetermine some environmental problems of agriculture. *High concentrations of sodium* in soils and/or irrigated waters lead to alkalinization. *High concentrations of toxic ions* (i.e. boron) can bring specific soil salinization.

The classification of natural factors determining water-related environmental problems of agriculture is shown in Table 4. As the task develops, the relations among these factors and environmental problems will be revised, possibly leading to a somewhat changed classification.

SCOPE OF THE STUDY

Two principal approaches exist to the study of natural phenomena within the system man-nature: experimental, including

Table 4. Classification of natural factors determining water-related environmental problems of agriculture.

Level	Factor	Main impact(s)	Determing factors
Regional	Climate (R/Lr,R)*	Type of agricultural activity (drainage, dry farming, irrigation)	Soils: genetic type, salt content, pH, humus content Natural biological productivity Water: resources available, salt content
	Relief (mean amplitude)	Erosion hazard (plus transport of chemical compounds with eroded soil)	Natural drainage of soils Depth of groundwater level
Field	Soil & ground (mechanical composition)	Natural drainage (leakage of chemical compounds)	Water holding capacity Height of capillary rise Water erosion
	Relief (angle and length of the slope)	Potential erosion	Nutrient content of soils
	Groundwater (depth in comparison with the plant roots depth)	Waterlogging and salinization	
	Specific geochemical features (e.g. high content of sodium or toxic ions)	Alkalinization Specific salinization	

*R is net solar radiation, r is precipitation, L is latent heat of evaporation, all on an average yearly scale [9].

passive experiments by observing changes occurring in nature, and model. An experimental approach permits us to collect a large amount of data to describe processes and on this basis to understand the pecularities of process development in space and time. However, this approach usually is not sufficient to forecast process development, especially where there are a number of economic policy options leading to different possible impacts on the environment.

The modeling approach is based, of course, on the experiments, which in principle permits us to forecast via a number of scenarios. However, in many cases the models are out of touch with reality. They may be so oversimplified that important features observed in experiments are omitted, or so complicated that many parameters and constants are hardly obtainable from the experiments. Besides, many models are of local character because their authors have not concerned themselves with wider applicability of the model.

It is obvious that the union of the experimental and the modeling approach should be closer, and it is our intention to use this approach. Geographic analysis could provide the basis for this union.

We have said that agriculture has certain impacts on the environment, which depend heavily on the natural conditions of an area. Hence, it would be useful to classify the dependence of typical sets of impacts on natural conditions. This would be useful both for further elaboration of the problem solution and for long-term regional planning.

From the point of view of application, there are two types of problems connected with the impacts of agriculture on the environment: those of operational control and those of long-term planning. The experiments and models related to these two types differ considerably. Existing models should be assessed also as to the time scale of their application.

The characteristics of field processes can be divided into two main groups: local (typical for the given field) and regional or zonal. We expect that a zonal classification of field parameters and their dependence on natural factors would assist in the assessment of applicability of both the experimental data and the models.

Agricultural impacts on the environment at the field level should be regarded as part of a more complex agriculture-environment system embracing both the other hierarchical levels (region, country) and components of the environment outside a given field (quality of surface water in hydrographic network, quality of groundwater, quality of air basins, etc.). In this respect, there is a coordination of efforts with other IIASA tasks, such as those dealing with national agricultural policy models or water quality models. Therefore, two classes of problems could be studied: the forecasting of impacts of agricultural activity on the environment, and, as the inverse task, the assessment of constraints on agricultural activity under the condition of keeping certain environmental standards.

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